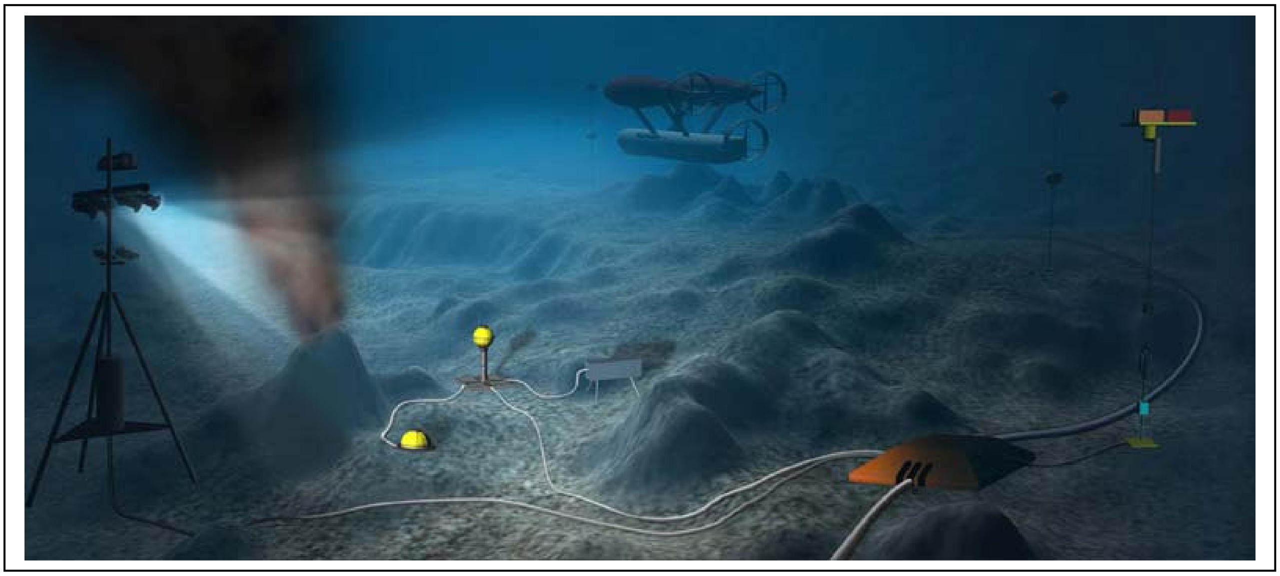
Regional Scale Nodes Preliminary Report Reliability and Availability Analysis

Version 1-03



Prepared by
University of Washington for the
Ocean Observatories Initiative
Dec 30, 2009

Document Number 4319-00001

Document Control Sheet

Version	Release Date	Description	By
1-03	12/30/09	Initial Version	M. Harrington

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1. Introduction

The Regional Scale Nodes (RSN) is an underwater cabled observatory off the coast of Oregon and Washington. It is part of a larger NSF funded Ocean Observatory Initiative (OOI) that also includes Coastal and Global Observatories and a Cyberinfrastructure. The RSN will bring continuous high power and high bandwidth to instruments on the seafloor and in the vertical water column. This infrastructure will allow for new ways to explore the science of the oceans compared to the traditional instruments that must work using batteries and intermittent radio links. The RSN uses a Primary Infrastructure to provide High Power at 10kW and High Bandwidth at 10Gbps to Sites across the Juan De Fuca plate using conventional telecom equipment built for long haul, high reliability subsea trans-ocean applications. The RSN uses a Secondary Infrastructure to connect instruments to the Primary Infrastructure using lower voltages and moderate bandwidths. The Secondary Infrastructure includes a set of Core Instruments that will provide measurements used to both answer Key Science Questions from day one and to provide a long term background context for future sensors that are added to the system. The subsea Primary Infrastructure is terminated at Shore Stations that have the Power Feed equipment and Network Line Termination equipment to drive the backbone cables out to the Sites. The Shore Stations are connected to Cyber Infrastructure CyberPops and the rest of the OOI through a backhaul system that connects the subsea data network to a telecom facility in Portland. The RSN has a design life of 25 years and the architecture supports future expansion.

For the system to be useful to Scientists and economical to maintain over the life of the system, the subsystem components must be reliable enough such that sensor data records are sufficiently continuous to provide long term records of the environment and observe unique or transient events.

This paper will give an overview of the RSN system and subsystem reliability and availability requirements as they currently exist in DOORs requirements database. This paper will also describe any analysis done or architectures chosen to support the reliability and availability requirements for each subsystem.

2. RSN Architecture Overview

The RSN uses a Primary Infrastructure to provide High Power at 10kW and High Bandwidth at 10Gbps to Sites across the Juan De Fuca plate using conventional telecom equipment built for long haul, high reliability subsea trans-ocean applications. The RSN uses a Secondary Infrastructure to connect instruments to the Primary Infrastructure using lower voltages and moderate bandwidths. The Secondary Infrastructure includes a set of Core Instruments that will provide measurements used to both answer Key Science Questions from day one and to provide a long term background context for future sensors that are added to the system. The subsea Primary Infrastructure is terminated at Shore Stations that have the Power Feed equipment and Network Line Termination equipment to drive the backbone cables out to the Sites. The Shore

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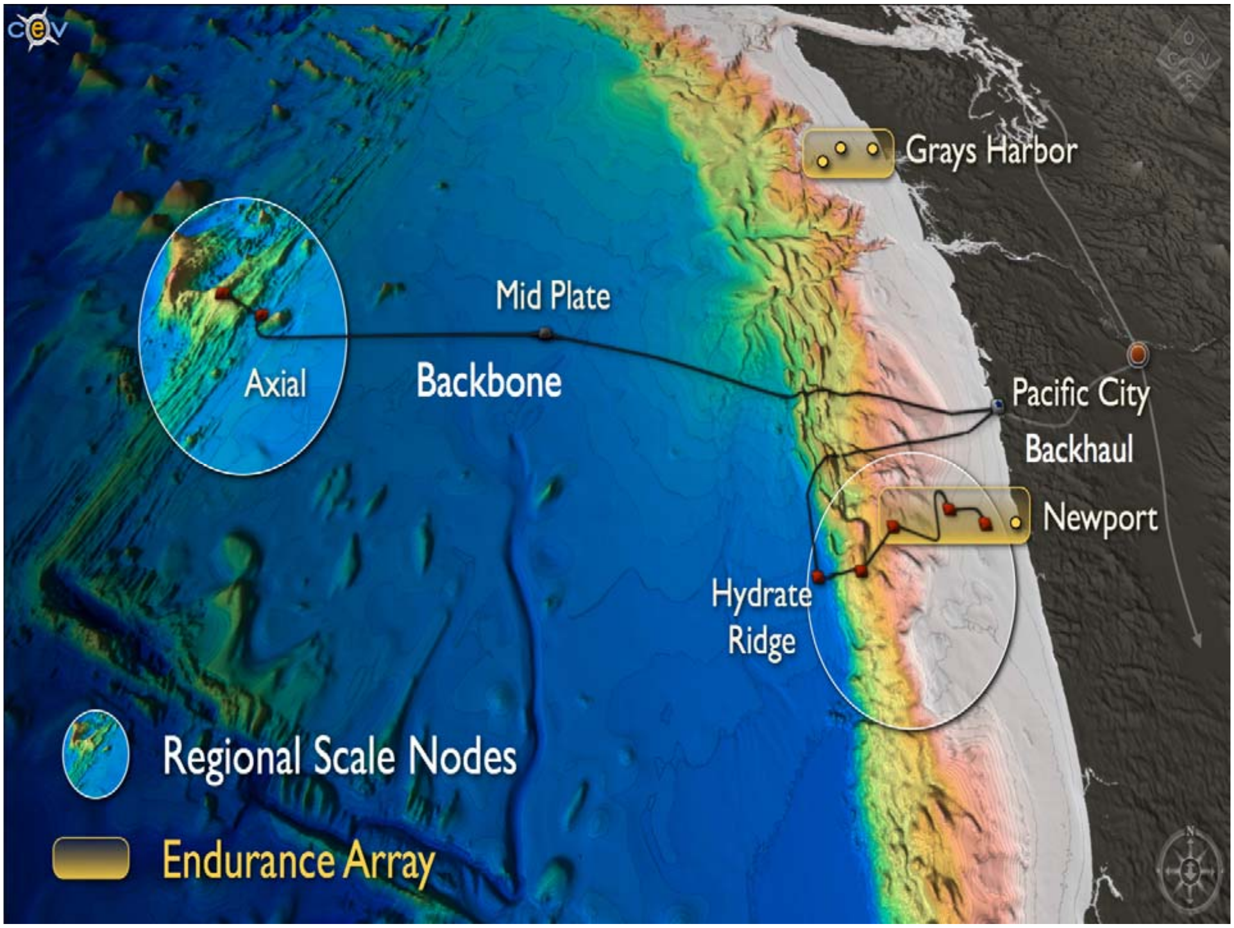
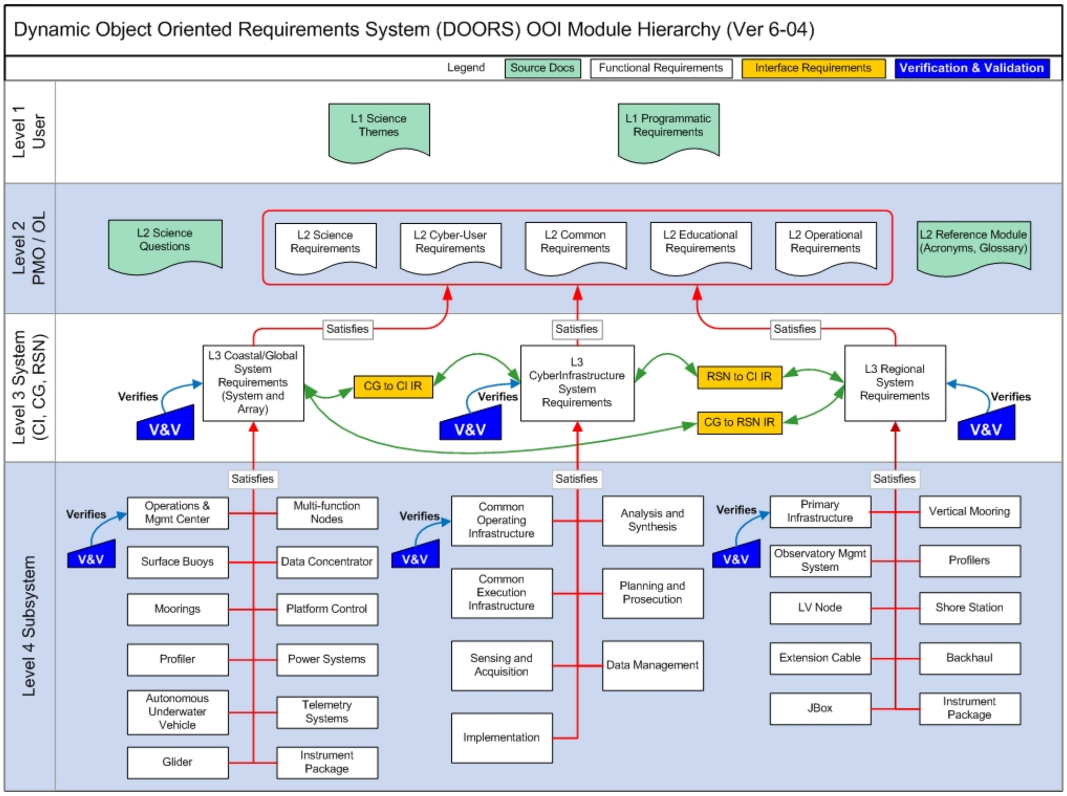


RSN Primary Infrastructure Node Locations

3. OOI System of System Requirements

The Requirements for the OOI have been captured in the DOORs requirements system. They have been separated into modules at 4 different level. The top level L1 requirements have been captured from the user community and NSF direction. Level 2 are further detailed user community requirements for the entire OOI. Level 3 are at the Implementing Organization level including the interface requirements between the IOs. Finally Level 4 has detailed IO subsystem requirements. Reliability requirements that flow down to the RSN live at the L2 and below level. The following sections list the requirements as they exist in DOORs. Preliminary Analysis on how subsystems will meet the requirements is given for L4.



OOI DOORs Module Hierarchy

3.1. L2 Operational and Maintenance Requirements

L2-OM-RQ-79	The OOI shall be maintained to be operable for a minimum of twenty-five (25) years.
L2-OM-RQ-92	The OOI shall provide at least single fault tolerance for all elements, where practical.
L2-OM-RQ-93	The OOI shall provide sufficient fault isolation to ensure that failures can be isolated to individual instruments nodes/ elements/ branches of the network as practicable.
L2-OM-RQ-113	All OOI infrastructure, instruments, systems and subsystems shall be operated to maximize the time intervals between maintenance, replacement, and cleaning.
L2-OM-RQ-120	A Failure Mode analysis and Reliability calculation shall be conducted on all critical operational OOI components, systems, and subsystems.

3.2. L2 Science Requirements

L2-SR-RQ-3270	The OOI shall make co-located measurements of geophysical, chemical, biological and water column properties at least one methane seep-gas hydrate deposit on the continental margin for at least 25 years.

L2-SR-RQ-3288	The OOI shall collect broadband seismic measurements in near real time for 25 years 95% of the time.
L2-SR-RQ-3609	In waters with a total depth less than 750 m, the OOI shall provide biofouling mitigation for submerged sensors and infrastructure to extend measurement capability as required for a deployment of 12 months.

3.3. L2 Common Requirements

L2-CR-RQ-83	The OOI infrastructure shall be designed to be operable for a minimum of twenty-five (25) years beginning with system acceptance with practicable maintenance within the NSF O&M budget guidance.
L2-CR-RQ-137	All of OOI, including all OOI IOs, shall approach all OOI initiatives with a purpose of minimization in life-cycle cost, including design, implementation, installation, operating, and maintenance costs.

3.4. L2 Reference Module

L2-RM-2132	System Design Life	The period of time commencing from the date of the Final Acceptance that the System is designed to operate in conformance with the Specifications without the need to replace key elements.

There are currently no definitions in the reference module for:

- Reliability
- Availability
- Serviceable Design Life
- Design Life

4. RSN System Requirements

4.1. RSN System Requirements

L3-RSN-RQ-94	The RSN System shall be designed to have a Serviceable Design Life of at least 25 years.
L3-RSN-RQ-332	The RSN System shall provide a monthly average availability of the Infrastructure to all instrument ports of at least 94%, except due to planned maintenance or external aggression.
L3-RSN-RQ-	All RSN System sub sea equipment shall be capable of long term storage and transportation in a temperature range of -20°C to +40°C without affecting the design life of the equipment.
L3-RSN-RQ-339	The RSN System shall not be corrupted over the Serviceable Design Life due to corrosion
L3-RSN-RQ-408	The RSN Primary Infrastructure shall have a Design Life of at least 25 years.
L3-RSN-RQ-152	The RSN IO shall provide for timely repair of Primary Infrastructure Components to meet system availability requirements.
L3-RSN-RQ-417	The Primary Infrastructure shall have a monthly availability of at least 99.5%

	excluding planned maintenance and external aggression.
L3-RSN-RQ-211	The Vertical Moorings shall have a Serviceable Design Life of 10 years.
L3-RSN-RQ-317	The Shore Stations shall provide sufficient Power backup capabilities such that the overall system availability can be met.
L3-RSN-RQ-307	The Backhaul Link shall have a monthly availability of at least 99.99%.

L3 RSN System Requirements

4.2. CI-RSN IRA Requirements

L3-CI-RSN-IA-128	The RSN-provided backhaul must have at least 0.9999 availability including scheduled maintenance of all backhaul equipment.
L3-CI-RSN-IA-129	The CI IO Portland CyberPop shall have at least 0.99999 availability including redundancy.

L3 CI-RSN IRA Requirements

5. RSN Sub System Requirements

5.1. Backhaul

L4-RSN-BH-RQ-61	The Backhaul shall have an overall monthly availability of at least 99.99%

L4 RSN Backhaul Requirements

Analysis:

There is a very high reliability requirement on the Backhaul system that connects the Shore Station to the CI CyberPop and Internet connection point in Portland. This high reliability requirement is driven by the architectural choice to put the Cyberpop in Portland. Here it will be easier for CI to install, support and expand their Point of Presence as it will be housed in a commercial leased space pre built for housing high reliability telecommunication equipment. Since the CI will be controlling the instruments on the seafloor from Portland, any disruption in this connection will result in lost data. It will not be possible to store/buffer data at the shore stations form the instruments if there is a loss in the backhaul connection.

The plan for implementing this system at day one is to use divergent leased lines such that any down time in one system due to external aggression, component failure or planned maintenance is covered by the second system. Common points of failure between the two systems will minimized to achieve the required system reliability. This is a low risk, common industry practice, with the down side of increased cost in providing the redundant system.

5.2. Primary Infrastructure

L4-RSN-PI-RQ-311	The Primary Infrastructure shall be designed to have a Design Life of at least 25 years.
L4-RSN-PI-RQ-78	There shall be at least a 95% confidence that no more than 2 Marine Repairs of sub-sea Primary Infrastructure components are required for each Cable Line over the Serviceable Design Life excluding failures due to external aggression.
L4-RSN-PI-RQ-81	There shall be at least a 95% confidence that all Primary Node Expansion, Science and High Bandwidth Ports have a Monthly Availability of at least 99.5% exclusive of the time needed to make Marine Repairs to sub-sea Primary Infrastructure components due to external aggression and planned maintenance.

L4 Primary Infrastructure Requirements

Analysis:

The Primary Infrastructure is being procured under a design, build fixed price contract. A technical specification reflecting the requirements in the DOORs database was part of an RFP process used to select a contractor. In the response to the RFP, the eventual winner of the contract provided a detailed analysis of their proposed system showing how it would meet the required availability and reliability requirements.

A number of key architectural decisions were made to meet this high availability requirement. The backbone cable and repeaters are components used in commercial trans-oceananic systems that are engineered to last 25 years with extremely high reliability and exacting standards as repairs are very expensive in both time and materials and lost revenue to the user of the system.

The Primary Nodes are a new component of the system. In order to eliminate the risk of using ROV wet mate at high voltages (~10 kV), all high voltage components, including the MVPC, are hard wired into the backbone cable. This means that any failure in the MVPC, which converts 10 kV down to 375 V, will require a cable ship for repair. Requirements allow for only 2 cable ship repairs per line over the 25 year life of the system. An analysis was done on a similar system deployed by the MVPC subcontractor. There were no failures reported over multi-year deployments in the few deployed cases. An additional analysis was provided showing the calculated reliability based on this field experience. Also, a total part analysis was done on the components in the controller section of the MVPC based on the BOM.

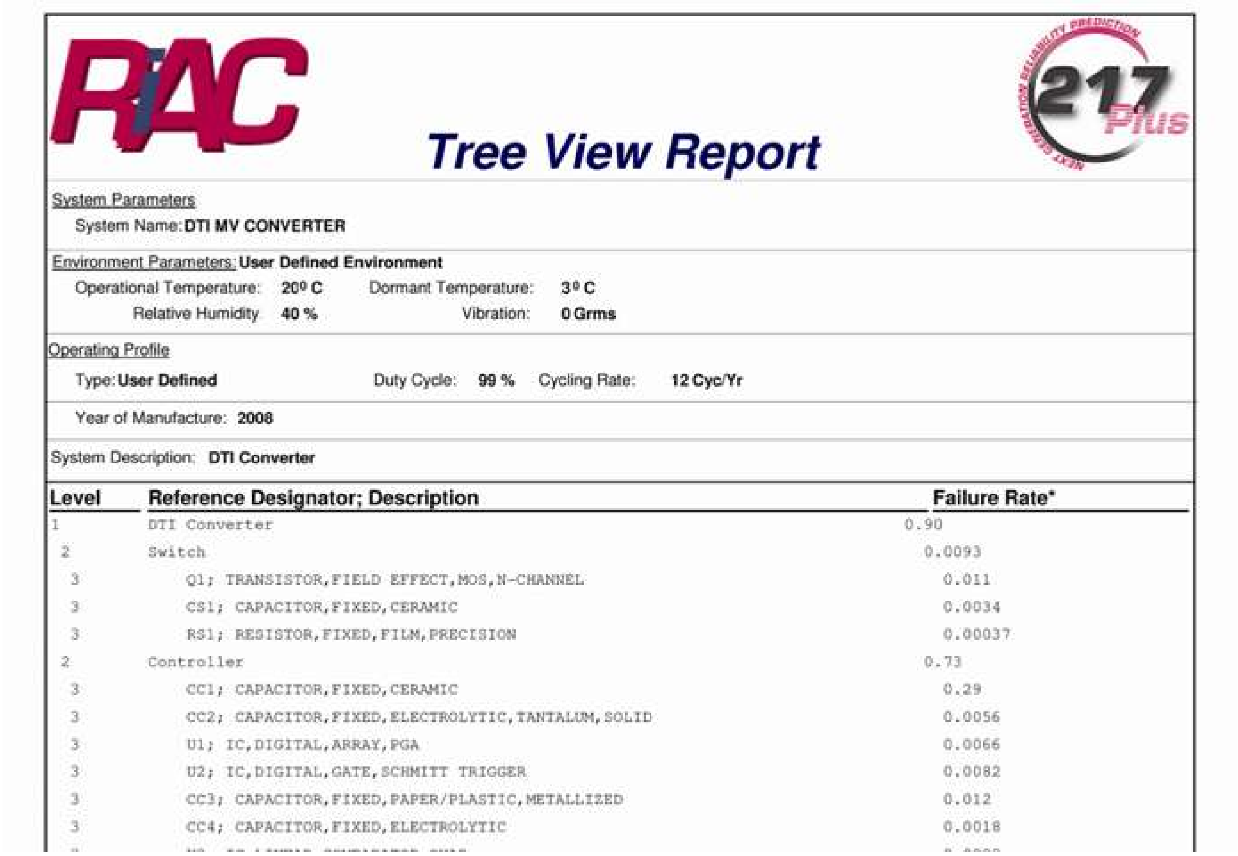
The MVPC is able to meet the high reliability requirement because of its simple design and because the critical components are configured in a redundant way such that the system will still be able to function in the face of multiple failures. The controller circuit may also be redundant but the decision to do so will not be completed until CDR.

The rest of the Primary Node runs at 375V and has more complicated and less reliable components such as network switches, low power controllers, and low power voltage supplies.

To meet the high availability requirements in this part of the Primary Infrastructure, the vendor has chosen to make most of the subcomponents redundant with failover capabilities such that no functionality is lost if a single component fails. When a component does fail, it is reported through the Management System and a scheduled maintenance can be planned for the following weather window to replace this part of the Primary Node using a UNOLS vessel with an ROV.

The contractor's calculations show that no more than one Primary Node servicing should be required each year.

L3 MariPro



Tree View Report

System Parameters
System Name: **DTI MV CONVERTER**

Environment Parameters: **User Defined Environment**
Operational Temperature: **20º C** Dormant Temperature: **3º C**
Relative Humidity **40 %** Vibration: **0 Grms**

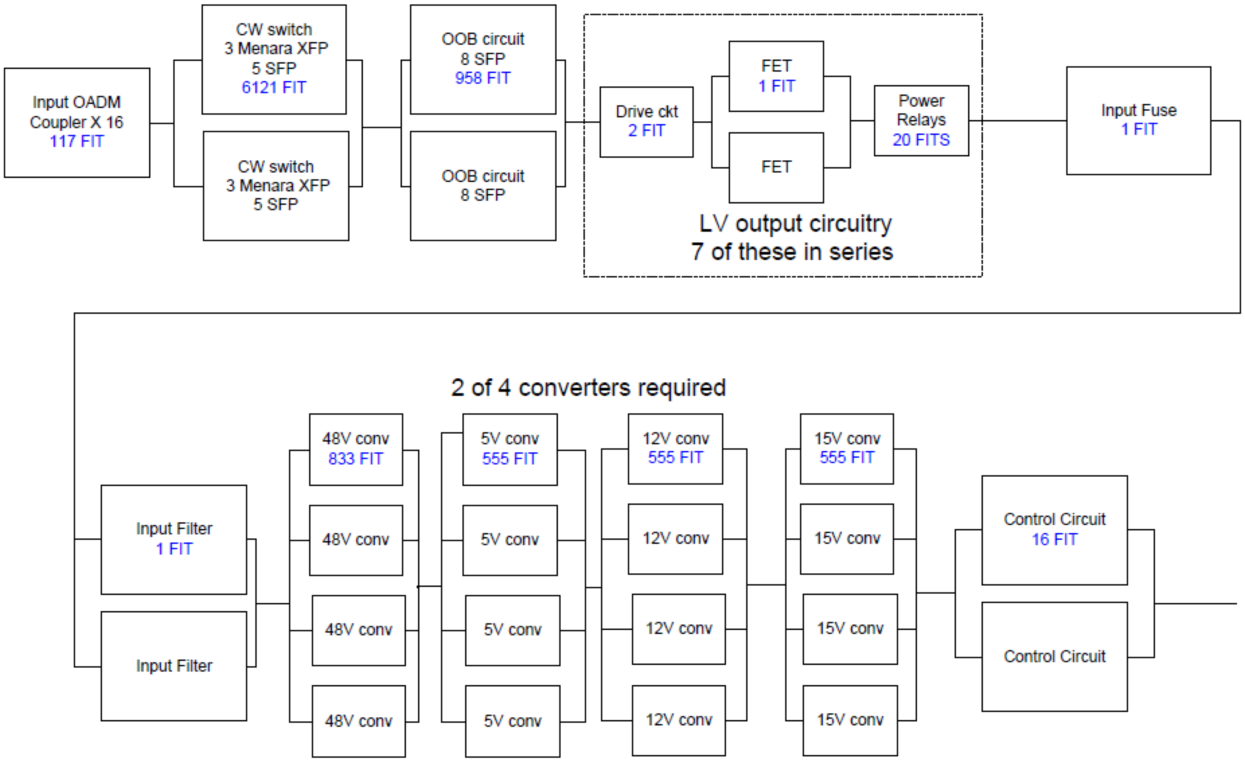
Operating Profile
Type: **User Defined** Duty Cycle: **99 %** Cycling Rate: **12 Cyc/Yr**

Year of Manufacture: **2008**

System Description: **DTI Converter**

Level	Reference Designator; Description	Failure Rate*
1	DTI Converter	0.90
2	Switch	0.0093
3	Q1; TRANSISTOR,FIELD EFFECT,MOS,N-CHANNEL	0.011
3	CS1; CAPACITOR,FIXED,CERAMIC	0.0034
3	RS1; RESISTOR,FIXED,FILM,PRECISION	0.00037
2	Controller	0.73
3	CC1; CAPACITOR,FIXED,CERAMIC	0.29
3	CC2; CAPACITOR,FIXED,ELECTROLYTIC,TANTALUM,SOLID	0.0056
3	U1; IC,DIGITAL,ARRAY,PGA	0.0066
3	U2; IC,DIGITAL,GATE,SCHMITT TRIGGER	0.0082
3	CC3; CAPACITOR,FIXED,PAPER/PLASTIC,METALLIZED	0.012
3	CC4; CAPACITOR,FIXED,ELECTROLYTIC	0.0018

Sample MTBF analysis based on component values.



Analysis of Primary Node SIA

The above figures show examples of some of the analysis and tools used by the Primary Infrastructure Vendor in their analysis of how they will meet the Reliability and Availability requirements. The full analysis was provided in their response to the RFP.

The Primary Node SIA is similar in functionality to the JBox/LVNodes in the Secondary Infrastructure so we will look at it more closely here. In the above figure each component is in the SIA is modeled with a FIT (failures in 10^9 hours) rate and either serial or parallel for redundant components. In this analysis if any part of the system fails the entire SIA will be considered failed, either a non redundant part or both sides of the redundant part. It is good to keep in mind that in some cases if one output port is failed the others would still be working but using this analysis the entire unit would still be considered failed.

Reliability (R) is the probability that a unit will work with out failure for a given mission time. For analysis done here it is assumed that there is a constant failure rate, which is typical for electronics equipment that has been burned in to avoid any infant mortality failure modes and not year in its wear out section of its lifetime. With this model, single value Mean Time Between Failure (MTBF) numbers can be arithmetically combined for subsystem to provide an overall system reliability number.

MTBF numbers can also be represented in Failures in Time (FIT) rates, which are have easier to use units.

To convert from a MTBF rate to a Reliability the following equation is used.

$\lambda(t)$= Constant Failure Rate
MTBF = 1/ $\lambda(t)$

The reliability for a given mission time and constant failure rate is:
$R_{sys} = e^{-\lambda t}$

The calculated reliability of an SIA(including redundancy) is
$R_{SIA}=R_{op}*R_{com}*R_{lv} = 0.999*0.991*0.999 = 0.989$ (98.9 % chance of no failures in 1 year)

$MTBF_{SIA} = -Tm/\ln(R_{SIA}) = -8760/\ln(0.989) = 791{,}975$ hours = 1262 FIT

Given a mean time to repair a failed SIA with both redundant components failed is 7 days:
MTTR(Mean Time To Repair) = 168 hours

Then the availability of single SIA is:
$Availability_{SIA} = MTBF/(MTBF+MTTR) = 0.9998$

Total Subsea System Availability
Includes BIA and SIA for all 7 Nodes and repeaters

$R_{tot} = R_{op}^{7}*R_{com}^{7}*R_{lv}^{7}*R_{rep}^{8}*R_{mv}^{7} = 0.912$

Rop = 0.999 - Optics
Rcom = 0.991 – Comms (including switch)
Rlv = 0.999 – Low Voltage Modules
Rrep = 1.00 – Repeaters (20FIT)
Rmv = 0.997 – Medium Voltage Converter

Assuming a 2000 hour MBTF of the Shore Station equipment and the about R total for the sub sea equipment and the following Mean Time to Repair numbers
$R_{tot} = 0.912$
$R_{shore} = 2000$ hours

$MTTR_{shore} = 4$ hours -
$MTTR_{sub} = 168$ hours

The availability of both the shore and sub sea equipment can be calculated
$Availability_{Shore} = 0.998$
$Availablity_{Sub} = 0.998$

And the total is the product of the two
$A_{total} = A_{shore}*A_{sub} = 0.996$

5.3. JBox/LVNodes

L4-RSN-JB-RQ-229	The JBox Seafloor Frame, Pressure Housing and any Wet Mate Connectors shall have design life of 25 years.
L4-RSN-JB-RQ-230	The JBox shall have a scheduled maintenance interval of at least 5 years.
L4-RSN-JB-RQ-231	The JBox Electronic Modules contained in the Pressure Housing shall have design life of 5 years.
L4-RSN-JB-RQ-232	The JBox shall have an average monthly instrument port availability of 97% excluding scheduled maintenance or external aggression.
L4-RSN-JB-RQ-188	The JBox shall have a 95% probability that it will have less than 1 failure in its 5 year operational cycle that requires an unscheduled maintenance recovery and repair operation.

L4 JBox Requirements

L4-RSN-LV-RQ-215	The LVNode Seafloor Frame, Pressure Housing and any Wet Mate Connectors shall have design life of 25 years.
L4-RSN-LV-RQ-216	The LVNode shall have a scheduled maintenance interval of at least 5 years.
L4-RSN-LV-RQ-217	The LVNode Electronic Modules contained in the Pressure Housing shall have design life of 5 years.
L4-RSN-LV-RQ-218	The LVNode shall have an average monthly science port availability of 97% excluding scheduled maintenance or external aggression.
L4-RSN-LV-RQ-173	The LVNode shall have a 95% probability that it will have less than 1 failure in its 5 year operational cycle that requires an unscheduled maintenance recovery and repair operation.

L4 LVNode Requirements

Analysis

LVNodes and Junction Boxes have very similar functionality and therefore reliability. They have an average science port availability requirement of 97% that assumes all of the upstream equipment is working correctly and there for excludes external aggression. It also excludes any time needed for scheduled maintenance.

This requirement combines with the probability that there will be a 95% chance of no failures (less than 1) in its 5 year Design Life that requires an unscheduled maintenance recovery and repair operation.

An LVNode is going to be installed for 5 years what is the FIT rate needed to ensure a probability of failure of less than 0.05?

5 years = 43,800 hours

$F(t) = 43,800 \text{ hours} = 1-e(-\lambda (43800))=0.05$

λ = (ln(1/(1-0.05))(1/43800)= 1.17x10-6 = 1170 FITs
MTBF = 1/1.17x10-6 = 854,000 hours

This calculated number is similar to the SIA estimated numbers for the Primary Infrastructure, but the SIA MTBF assumes that there is full redundancy in the Communication equipment including the switch and SFP cards.

If we only chose to repair an LVNode during its regular maintenance cycle the MTTR is 6 months

MTTR = 4380 hours

A_{lvnode}= 854000/(854000+4380) = 0.994

If we choose not to use a redundant switch in the Nodes and we use just the MTBF for a typical industrial switch of 4000 FITs(the military grade SIA switch had a FIT rate of 2000) plus 3 SFP cards at 350 FITs each we get a FIT rate of 5000. (this number does not include power supplies, control electronics and output drivers so the actual number probably will be significantly higher)

Now the MTBF of the Node = 200,000 hours

And the probability that there will not be a failure in 5 years is:

$R = e^{-\lambda t =} e^{-(1/200{,}000)(43{,}800)} = 0.80$

A_{lvnode}= 200000/(200000+4380) = 0.978

6. Conclusion/Future Effort

The RSN System will only be successful if it's a reliable system over its entire design life. Because of the expense in servicing the sub-sea infrastructure especially for unscheduled emergency repairs it is important to design using very reliable subsystem and use redundancy where appropriate.

The strategy for the RSN system is to have a higher reliability for the Backhaul and Primary Infrastructure and then a moderate reliability for the Secondary Infrastructure. This is because a larger part of the system will be effected by a part of the Primary Infrastructure failing and all sensor data will be lost if the Backhaul System fails.

This paper reviewed the current state of the RMA requirements at the System of System, System and Sub-system level. The Primary Infrastructure has a fully worked out Availability and Maintenance strategy as provided as part of the Contractors response to the RFP.

Further work needs to be done to refine the requirements for both the Secondary Infrastructure and to make sure the full system requirements are fulfilled by each of the subsystems requirements. Also definitions such as Reliability, Availability, Average Port Availability, and Design Life need to be defined for both RSN and the OOI.